

2. RAW MATERIALS ACQUISITION AND MANUFACTURING

To estimate the GHG emissions and sinks for the full life cycle of MSW materials, we needed to estimate the GHG emissions associated with raw materials acquisition and manufacturing. This chapter describes how we estimated these emissions for eight materials: newspaper, office paper, corrugated boxes, aluminum cans, steel cans, and three types of plastic (LDPE, HDPE, and PET).

In manufacturing, substantial amounts of energy are used in the acquisition of raw materials and in the manufacturing process itself. In most processes, the majority of this energy comes from fossil fuels. Combustion of fossil fuels results in emissions of CO₂, a greenhouse gas, and trace amounts of other GHGs that are not included in the analysis. In addition, manufacturing of some materials also results in GHG emissions that are not associated with energy consumption. Section 2.1 addresses energy-related CO₂ emissions, and section 2.2 covers non-energy GHGs.

2.1 GHG EMISSIONS FROM ENERGY USE IN RAW MATERIALS ACQUISITION AND MANUFACTURING

To begin our analysis, we estimated the GHG emissions from fossil fuel combustion for both (1) raw materials acquisition and manufacturing (referred to here as "process energy"), and (2) transportation (referred to as "transportation energy").

In this analysis, process energy GHG emissions consist primarily of CO₂.²⁴ The majority of CO₂ emissions are from combustion of fuels used directly, e.g., to operate mining equipment or to fuel a blast furnace. Because fuel is also needed for "pre-combustion" activities (such as oil exploration and extraction, coal mining and beneficiation, and natural gas production), CO₂ emissions from "pre-combustion" activities are also counted in this category. When electricity is used in manufacturing, the CO₂ emissions from the fuels burned to produce the electricity are also counted. In general, making a material from recycled inputs requires less process energy than making the material from virgin inputs.

Transportation energy GHG emissions consist of CO₂ emissions from combustion of fuels used to transport raw materials and intermediate products to the final manufacturing or fabrication facility. For transportation of recycled inputs, this analysis considers transportation (1) from the curbside to the materials recovery facility (MRF),²⁵ (2) from the MRF to a broker, and (3) from a broker to the plant or mill where the recycled inputs are used. The transportation values for recycled inputs also generally include the energy used to process the inputs at a MRF.²⁶ Transportation of finished manufactured goods

²⁴ Note, however, that CO₂ emissions from combustion of biomass are not counted as GHG emissions (as described in Chapter 1). For example, paper manufacturing uses biomass as a fuel.

²⁵ A MRF processes recovered materials from the municipal solid waste (MSW) stream. Some MRFs take mixed MSW and separate recyclable materials. Other MRFs accept only source-separated recyclable materials. MRFs may crush, shred, or bale recyclable materials to make them ready for the scrap materials market.

²⁶ The one exception is that data provided by Franklin Associates, Ltd. do not include the energy used in a MRF to sort paper products.

to consumers is not included in the analysis. We did not consider the global warming impacts of transportation emissions of nitrogen oxides (NO_x); such emissions contribute indirectly to climate change.²⁷ This omission would tend to slightly understate the GHG impacts from transportation.

We also considered the methane emissions associated with producing, processing, and transporting coal, oil, and natural gas. Methane is emitted during the various stages of fossil fuel production because methane is trapped within coal and oil deposits, and because natural gas consists largely of methane.

We developed separate estimates for GHG emissions from process and transportation energy for virgin inputs and recycled inputs, generating a total of four separate GHG emissions estimates for each material: (1) process energy with virgin inputs, (2) process energy with recycled inputs, (3) transportation energy with virgin inputs, and (4) transportation energy with recycled inputs.

Methodology

We developed GHG emission estimates for each material based on two sets of data: (1) the amount of each type of fuel used to make one ton of the material, and (2) the "carbon coefficient" for each fuel (a factor that translates the energy value of fuel combusted into the mass of GHGs emitted).

Our methodology in using these two sets of data to estimate process and transportation energy GHG emissions is best illustrated by an example. To estimate process energy GHG emissions from the production of one ton of newspapers from virgin inputs, we multiplied the amount of each type of fuel used (as measured in million British thermal units, or BTUs) times the carbon coefficient for that type of fuel (as measured in metric tons of carbon equivalent, or MTCE, per million BTUs). Each of these multiplications yielded an estimate, for one of the fuels used to make newspaper, of the amount of GHGs emitted (in MTCE) from the combustion of that fuel when one ton of newspaper is made. The total process energy GHGs from making one ton of newspaper is simply the sum of the GHG estimates across the different fuels used. To estimate the GHG emissions when electricity is used, we used the national average mix of fuels used to make electricity.

We estimated GHGs from the energy used to transport raw materials for making one ton of a given product (e.g., newspapers) in the same way: the amount of each fuel used was multiplied by its carbon coefficient, and the resulting values for each of the fuels were summed.

To count "pre-combustion" energy, we scaled up the amount of each fuel combusted during manufacture by the amount of energy needed to produce that fuel. In this approach, we used the simplifying assumption that when oil is produced, oil is used as the energy source in oil production, while natural gas is used for natural gas production, etc.

We developed GHG estimates for raw materials acquisition and manufacturing for each of the eight manufactured materials of the ten materials considered in this report. We also developed GHG estimates

²⁷ Because the Intergovernmental Panel on Climate Change (IPCC) has not established a method for estimating the global warming implications of emissions of nitrogen oxides, we have not attempted such an estimation.

for tissue paper and folding boxes to enable us to estimate the GHG implications of increased recycling of office paper and corrugated boxes, respectively, in an "open loop." Thus, the exhibits in this chapter show data not only for the eight materials of interest, but also for tissue paper and folding boxes. For steel cans, we developed GHG estimates for virgin production using the basic oxygen furnace process, and for recycled production using the electric arc furnace process.²⁸

For the first set of data that we needed (the amounts of each type of fuel used for process and transportation energy), we obtained two independent sets of estimates from two consulting firms that have expertise in lifecycle analysis, including process and transportation energy analysis: Franklin Associates Ltd. (FAL), and the Tellus Institute (Tellus). For the second set of data (carbon coefficients), we used data from the Energy Information Administration of the US Department of Energy²⁹ for all fuels except diesel fuel and electricity; for the latter fuels we used data from the American Council for an Energy-Efficient Economy.³⁰ The carbon coefficient for electricity was based on the weighted average carbon coefficients for all fuels used to generate electricity in the US.³¹

Because the carbon coefficients from these sources accounted for only the CO₂ emissions from combustion of each type of fuel, we added to these carbon coefficients (1) the average amount of methane emitted during the production, processing, and transportation of fossil fuels, and (2) the average CO₂ emissions from oil production, due to the flaring of natural gas. To estimate these GHG emissions associated with fossil fuel production, we used data from EPA, the US Department of Energy, and the Intergovernmental Panel on Climate Change. We calculated the average GHG emissions associated with US production of coal, oil, and natural gas. The resulting estimates for GHG emissions from fossil fuel

²⁸ Note that when recovered steel cans are used as inputs to an electric arc furnace, the resulting steel is not suited for milling to the thinness of steel sheet needed for use in making new steel cans. Thus, a more precise approach would have been to model recovery of steel cans as an open loop process, in which recovered steel cans are made into some other steel product. By modeling recovery of steel cans as a closed loop process, we implicitly assumed that each ton of steel produced from recovered steel cans in an electric arc furnace displaces a ton of steel produced from virgin inputs in a basic oxygen furnace; we believe this is a reasonable assumption. (For the fabrication energy required to make steel cans from steel, we used the values for fabrication of steel cans from steel produced in a basic oxygen furnace.)

²⁹ Energy Information Administration, U.S. Department of Energy, Draft *Emissions of Greenhouse Gases in the United States 1989-1994*, DOE/EIA-0573-annual (Washington, D.C.: U.S. Department of Energy), in press 1995, cited in U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1994* (Washington, D.C.: U.S. EPA), November 1995, pp. A-8 to A-13.

³⁰ R. Neal Elliott, Carbon Reduction Potential from Recycling in Primary Materials Manufacturing" (Berkeley, CA: American Council for an Energy-Efficient Economy), February 8, 1994, p. 14.

³¹ FAL and Tellus reported the BTU value for electricity in terms of the BTUs of fuel combusted to generate the electricity used at the factory, rather than the (much lower) BTU value of the electricity that is delivered to the factory. Thus, FAL and Tellus had already accounted for the efficiency of converting fuels to electricity, and the losses in transmission and distribution of electricity; and we did not need to account for these factors in the carbon coefficient for electricity.

production were 1.07 kilograms of carbon equivalent per million BTUs (kg C/million BTU) for coal, 0.23 kg C/million BTU for oil, and 0.82 kg C/million BTU for natural gas.³²

The carbon coefficients that reflect both CO₂ and methane emissions are provided in Exhibit 2-1 (all exhibits are provided at the end of this chapter).

The process and transportation GHG values are shown in summary form in Exhibit 2-2. For each product and each type of input (virgin or recycled), we summed the estimates for process and transportation GHG emissions based on the FAL data, and then repeated the summation using the Tellus data. Both sets of summed estimates are listed in Exhibit 2-2 in columns "b" (for virgin inputs) and "c" (for recycled inputs). Although these estimates do not represent minimum or maximum values, we believe that they do portray the variability in actual industry values for each material.

We also estimated the energy-related GHG emissions from manufacturing each material from the current mix of virgin and recycled inputs. To do so, we averaged the two estimates for each material based on FAL and Tellus data; the results are shown in column "e." (The remaining two columns of Exhibit 2-2 are discussed later in this chapter.)

The FAL and Tellus values for energy use are provided in Exhibits 2-3 through 2-10. Exhibits 2-3 through 2-6 present the FAL data providing, in turn, the data used to estimate energy-related GHG emissions for products manufactured from virgin inputs, and then the data for energy-related GHG emissions for products manufactured from recycled inputs.³³ Exhibits 2-7 through 2-10 present the Tellus data, which are organized in the same way.³⁴

For most materials, both FAL and Tellus provided data for fuels used in manufacturing processes that use (1) 100 percent virgin inputs and (2) 100 percent recycled inputs.³⁵ To estimate the types and

³² Memorandum from William Driscoll (ICF) to Michael Podolsky and Clare Lindsay (U.S. EPA), "Fugitive Methane Emissions from Production of Coal, Natural Gas, and Oil," August 8, 1995, updated to use global warming potential for methane of 24.5.

³³ Note that when newspaper is made from virgin inputs, a substantial amount of biomass fuel (e.g., from tree bark) is used; when newspaper is made from recycled inputs, no biomass fuel is used.

³⁴ Note that in Exhibits 2-7 and 2-9, Tellus included values for the energy content of steam used in manufacturing. We translated these steam energy values into fuel inputs as follows: (1) we assumed that the energy content of the fuels combusted was converted into steam energy at a conversion efficiency of 85 percent; (2) for paper products, made from virgin or recycled inputs, we used a fuel mix for steam of 40 percent oil, 33 percent biomass, 17 percent natural gas, and 10 percent coal; and (3) for non-paper products made from virgin or recycled inputs, we used a fuel mix for steam of 50 percent natural gas, 25 percent coal, and 25 percent oil (based on ICF professional judgment).

³⁵ The three exceptions were (1) the FAL data for corrugated boxes made from virgin inputs, for which FAL provided data for manufacture from 90.2 percent virgin inputs and 9.8 percent recycled inputs, (2) the FAL data for steel cans made from virgin inputs, for which FAL provided data for manufacture from 80 percent virgin inputs and 20 percent recycled inputs, and (3) the Tellus data for steel cans made from virgin inputs, for which Tellus provided data for manufacture from 90 percent virgin inputs and 10 percent recycled inputs. We extrapolated from these data (and the corresponding values for production using 100 percent recycled inputs) to obtain estimates of the energy inputs for manufacturing these materials from 100 percent virgin inputs.

amounts of fuels used for process and transportation energy, FAL and Tellus relied on published data (such as engineering handbooks and published production data), and on personal contacts with industry experts. FAL and Tellus counted all energy, no matter where it was used. For example, much aluminum produced in the US is made from bauxite that is mined and processed into alumina in other countries. The energy required for overseas bauxite mining and processing is counted in the analysis. In addition, it does not matter where recycled inputs are made into remanufactured products. For example, if office paper that is recovered in the US is remanufactured into paper products in Asia, the energy savings from remanufacture using recycled rather than virgin inputs are counted.

Neither the FAL nor the Tellus transportation data reflect transportation of the finished manufactured product to the retailer and consumer. This omission is only important in estimating the GHG reductions associated with source reduction. It is not relevant in analyzing GHG implications of recycling compared to other post-consumer management options, because the amount of transportation energy from the factory to the consumer is about the same whether the product is manufactured from virgin inputs or recycled inputs. Even for the source reduction analysis, we expect that the transportation energy from factory to consumer would represent a very small fraction of the total process and transportation energy.

After FAL and Tellus had developed their initial estimates of process energy intensity and fuel mix, we reviewed and verified the data by analyzing significant discrepancies between the estimates provided by the two firms. Where discrepancies were found, we reviewed the most critical assumptions and data elements that each firm used, and identified circumstances where it would be appropriate for one firm to revise its assumptions or update its data sources.¹² The effect of this process was to arrive at estimates by the two firms that were closer to each other and, we expect, that more accurately reflect the energy used in raw materials acquisition and manufacturing of the materials considered. Nevertheless, we recognize that different manufacturers making the same product use somewhat different processes with different energy requirements and fuel mixes, and that there are limited data on the extent to which various processes are used. Thus, our goal was to estimate as accurately as possible the national average GHG emissions for the manufacture of each material from virgin and recycled inputs.

In order to make the best use of all available data, for each material we averaged the FAL and Tellus final estimates of GHG emissions for manufacturing the material from virgin inputs, and then did the same for recycled inputs. These averaged values are used in all of the computations displayed in the executive summary and in Chapter 8, which present overall results of the analysis.

Complete documentation of the FAL and Tellus data on the types and amounts of fuels used for process and transportation energy, including data sources, is provided in the Appendix to this report.

¹² For example, some of the data issues that we reviewed and decided on were (1) the fuel mix to assume for electricity used to manufacture aluminum (the national average fuel mix for generating electricity was used, because electricity generated from all types of fuel is sold as a single commodity through interconnected regional grids), (2) whether to include the "pre-combustion" energy for fossil fuels, i.e., the energy required to extract, refine, and deliver the fuels (pre-combustion energy was counted), (3) whether to use data for use of recovered materials in "closed loop" or "open loop" processes (we used "closed loop" data except for office paper and corrugated boxes), and (4) what loss rates should be used (we averaged the FAL and Tellus loss rates).

2.2 NON-ENERGY GHG EMISSIONS FROM MANUFACTURING AND RAW MATERIALS ACQUISITION

We also accounted for three additional sources of GHGs in manufacturing processes that are not related to energy use:

- When limestone (calcium carbonate, or CaCO_3) is converted to lime (calcium oxide, or CaO), CO_2 is emitted. Significant quantities of lime are used in the production of steel, aluminum, and, to a much lesser extent, office paper.
- Methane emissions from natural gas pipelines and processing of natural gas are associated with the manufacture of plastic products.
- Perfluorocarbons (CF_4 and C_2F_6) are emitted during aluminum smelting.

In most cases, process non-energy GHG emissions are only associated with production using virgin inputs. In the case of steel, however, these emissions result when either virgin or recycled inputs are used (because lime is used in the production of steel from recycled as well as virgin inputs).

The process non-energy GHGs for each material are shown in the last column of Exhibits 2-3 and 2-5 (for manufacture from virgin inputs and recycled inputs, respectively), and are repeated in column "f" of Exhibit 2-2. Our source for all these data, except the perfluorocarbon emissions, is an appendix to a report prepared for the EPA Office of Policy, Planning, and Evaluation.¹³ Our source for the perfluorocarbon emissions is a memorandum prepared by ICF.¹⁴

2.3 RESULTS

Our estimates of the total GHG emissions from raw material acquisition and manufacturing for each material are shown in Exhibit 2-2, column "g." To obtain these estimates, we summed the energy-related GHG emissions (column "e") and the non-energy GHG emissions (column "f").

The process and transportation GHG values that were developed as described earlier in this chapter are shown in the second to last columns of Exhibits 2-3 and 2-5, and in the last columns of Exhibits 2-4 and 2-6 through 2-10 (the last columns of Exhibits 2-3 and 2-5 show the process non-energy GHG emissions, as noted above).

Because we had two independent sets of data on the amounts of each type of fuel used in making each product, we were able to develop both range estimates and point estimates of the energy-related GHG values for manufacturing each material from virgin or recycled inputs, and from the current mix of virgin and recycled inputs. In this report, for purposes of analyzing the GHG emissions associated with the

¹³ Memorandum from William Driscoll, Randy Freed, and Sarah Stafford (ICF) to Brett Van Akkeren (U.S. EPA), "Detailed Analysis of Greenhouse Gas Emissions Reductions from Increased Recycling and Source Reduction of Municipal Solid Waste," July 29, 1994, p. 48 of the Appendix prepared by Franklin Associates, Ltd., dated July 14, 1994.

¹⁴ Memorandum from William Driscoll, Doug Keinath, and Randy Freed (ICF) to Eugene Lee and Clare Lindsay (U.S. EPA), "Perfluorocarbon Emissions from Aluminum Smelting," March 27, 1996.

manufacturing stage of the product lifecycle, we are using the values in column "g" for total manufacturing GHG emissions (i.e., averages of point estimates). Depending on the inputs being considered, the appropriate value for total GHG emissions is used (i.e., the value for manufacture from virgin inputs, recycled inputs, or the current mix of virgin and recycled inputs).

2.4 LIMITATIONS

There are numerous limitations to the analysis of the GHG emissions associated with raw materials acquisition and manufacturing, as described below.

The approach used in this analysis provides values for the average GHG emission rates per ton of material produced, not the marginal emission rates per incremental ton produced. In some cases, the marginal emission rates may be significantly different. For example, reducing production of plastic products from virgin inputs may not result in a proportional decrease in methane emissions from natural gas pipelines and natural gas processing. Natural gas pipeline methane emissions are determined by the operating pressure in natural gas pipelines, and the number and size of leaks in the pipeline. Consequently, the amount of natural gas consumed at one end of the pipeline (e.g., to make plastic) does not affect the level of pipeline methane emissions in a direct, linear way.¹⁵ As another example, long-term reductions in electricity demand could selectively reduce demand for specific fuels, rather than reducing demand for all fuels in proportion to their representation in the current average fuel mix. This analysis estimates average carbon conversion rates largely because the marginal rates are much more difficult to estimate. Nevertheless, we believe the average values provide a reasonable approximation of the GHG emissions.

In addition, the analysis assumes that the GHG emissions from manufacturing a given product change in a linear fashion as the percentage of recycled inputs moves from 0 percent to 100 percent. In other words, the analysis assumes that both the energy intensity and the fuel mix change in linear paths over this range. However, it could be that GHG emissions from manufacturing move in a non-linear path, (e.g., some form of step function) when the percentage of recycled inputs changes, due to capacity limits in manufacturing or due to the economics of manufacturing processes.

The transportation energy required for the final stage of transportation (to the consumer) was not considered. Consequently, some carbon emissions reductions for "lightweighted" products for these transportation stages were not considered; these savings are likely to be negligible.

Finally, this static analysis does not consider potential future changes in energy usage per unit of output. Reductions in energy inputs, due to efficiency improvements, could occur in either virgin input processes or recycled input processes. Efficiency improvements will directly result in carbon emissions reductions, and may change the amount of carbon reductions possible through increased recycling or source reduction.

¹⁵ Bob Lott, Gas Research Institute, personal communication with William Driscoll, ICF Incorporated, June 30, 1995.

**Exhibit 2-1
Carbon Coefficients
For Selected Fuels**

Fuel Type	kg CO₂-C from Combustion Per Million BTUs	kg CO₂-C from Fugitive Methane Emissions Per Million BTUs	kg CO₂-C Emitted Per Million BTUs Consumed
Gasoline	19.43	0.23	19.66
LPG	17.02	0.23	17.25
Distillate Fuel	19.95	0.23	20.18
Residual Fuel	21.49	0.23	21.72
Diesel	20.80	0.23	21.03
Oil/Lubricants	20.24	0.23	20.47
Steam (non-paper products)	18.70	0.73	19.43
Steam (paper products)	13.12	0.34	13.46
National Average Fuel Mix for Electricity	16.24	0.68	16.92
Coal Used for Electricity	25.71	1.07	26.78
Coal Used by Industry (Non-Coking Coal)	25.61	1.07	26.68
Natural Gas	14.47	0.82	15.29
Other (Petroleum Coke)	27.85	0.23	28.08

Exhibit 2-2
Greenhouse Gas Emissions from the Manufacture of Selected Materials
(Metric Tons of Carbon Equivalent (MTCE) per Ton of Product)

(a) Type of Product	(b) Virgin Input Combined Process and Transportation Energy GHG Emissions (MTCE Per Ton of Product Made With Virgin Inputs)		(c) Recycled Input Combined Process and Transportation Energy GHG Emissions (MTCE Per Ton of Product Made With Virgin Inputs)		(d) Percent Recycled Inputs in the Current Mix of Virgin and Recycled Inputs		(e) Current Mix Combined Process and Transportation Energy GHG Emissions (MTCE Per Ton of Product Made with the Current Mix of Virgin and Recycled Inputs)		(f) Process Non-Energy GHG Emissions (MTCE Per Ton of Product)			(g) Average Combined Process and Transportation Energy and Process Non-Energy GHG Emissions (MTCE Per Ton of Product)		
	FAL Est.	Tellus Est.	FAL Est.	Tellus Est.	FAL Est.	Tellus Est.	FAL Est.	Tellus Est.	Virgin Inputs	Recycled Inputs	Current Mix	Virgin Inputs	Recycled Inputs	Current Mix
Newspaper	0.54	0.56	0.39	0.38	37%	33%	0.49	0.50	0.00	0.00	0.00	0.55	0.39	0.49
Office Paper	0.57	0.53	0.50	0.42	27%	29%	0.55	0.50	0.01	0.00	0.01	0.56	0.46	0.53
Tissue Paper	0.67	0.51	0.50	0.37			0.67	0.51	0.01	0.00	0.01	0.60	0.43	0.60
Corrugated Boxes	0.28	0.48	0.34	0.54	36%	43%	0.30	0.51	0.00	0.00	0.00	0.38	0.44	0.40
Folding Boxes	0.42	0.51	0.38	0.56			0.42	0.51	0.00	0.00	0.00	0.47	0.47	0.47
Aluminum Cans	4.30	3.73	0.69	0.76	54%	53%	2.35	2.17	1.49	0.00	0.69	5.51	0.72	2.95
Steel Cans	0.79	0.98	0.28	0.31	39%	46%	0.60	0.67	0.24	0.24	0.24	1.12	0.53	0.87
HDPE	0.52	0.79	0.25	0.32	1%	1%	0.51	0.79	0.07	0.00	0.07	0.72	0.29	0.72
LDPE	0.63	1.06	0.23	0.43	8%	8%	0.60	1.01	0.07	0.00	0.06	0.91	0.33	0.87
PET	0.98	1.30	0.41	0.50	28%	26%	0.82	1.09	0.04	0.00	0.03	1.18	0.46	0.98

Explanatory notes: To estimate the GHG emissions from manufacturing, we first estimated the process and transportation GHG emissions when 100 percent virgin inputs, or 100 percent recycled inputs, are used. For each product and each type of input (virgin or recycled), we first summed the estimates for process and transportation GHG emissions based on the FAL data, and then repeated the summation using the Tellus data. These summed estimates are shown above in columns "b" (for virgin inputs) and "c" (for recycled inputs). Two summed estimates are shown for each material in each column: the "FAL estimate" and the "Tellus estimate."

Next we estimated the GHG emissions from manufacturing each material from the current mix of virgin and recycled inputs. We began with estimates of the percentage of recycled inputs currently used in the manufacture of each material, as shown in column "d." We used these percentages to develop a weighted average value for the GHG emissions associated with the manufacture of each material from the current mix of virgin and recycled inputs. Specifically, we used the FAL estimate of the percentage of recycled inputs in the current mix, together with the FAL estimates for GHG emissions from manufacture using virgin or recycled inputs, to develop FAL estimates of GHG emissions from manufacture using the current mix of virgin and recycled inputs (labeled "FAL estimate" in column "e"). We repeated the process using the Tellus data (labeled "Tellus estimate" in column "e").

Explanatory notes for Exhibit 2-2 (continued): Column "f" shows estimates of the process non-energy GHG emissions from manufacturing. First this column shows the process non-energy GHG emissions when virgin inputs are used. Then it shows the emissions when recycled inputs are used (these values are simply copied from the final columns of Exhibits 2-3 and 2-5). Finally, column "f" shows the process non-energy GHG emissions from manufacturing each product from the current mix of virgin and recycled inputs. The values for the current mix are the weighted averages of the values for virgin and recycled inputs, based on the percentage of recycled inputs used in the current mix (as shown in column "d").

The total GHG emissions from manufacturing are shown in column "g." This column shows total GHG emissions when a product is manufactured from virgin or recycled inputs, or from the current mix of virgin and recycled inputs. To obtain these values, we first developed two estimates of the GHG emissions for each material and each set of inputs. One estimate is based on FAL data, and the other is based on Tellus data (these estimates included both energy-related GHG emissions and process non-energy GHG emissions). The values in column "g" are the averages of the estimates based on FAL and Tellus data.

Exhibit 2-3 (Franklin Data)
Amount of Carbon Produced Per Ton of Product Manufactured from Virgin Inputs
Process GHGs Only

Type of Product	Process Energy (Million BTUs Per Ton of Product)	Average Fuel Mix (in Percent)										Process Energy Carbon Emissions (MTCE/Ton of Product)	Process Non-Energy Carbon Emissions (MTCE/Ton of Product)
		Gasoline	LPG	Distillate Fuel	Residual Fuel	Biomass	Diesel	Electricity	Coal	Natural Gas	Total		
Newspaper	33.96	0.00	0.06	0.08	0.49	6.53	0.82	57.54	1.07	33.41	100.00	0.52	0.00
Office Paper	54.80	1.99	0.00	0.01	4.34	50.07	0.00	24.75	9.78	9.06	100.00	0.52	0.01
Tissue Paper	52.09	2.29	0.00	3.35	13.19	40.88	0.00	18.90	11.95	9.44	100.00	0.62	0.01
Corrugated Boxes	30.01	0.00	0.00	0.01	1.62	56.06	1.21	19.67	8.75	12.68	100.00	0.25	0.00
Folding Boxes	40.12	2.79	0.00	1.44	5.88	47.87	0.00	18.22	10.29	13.52	100.00	0.40	0.00
Aluminum Cans	243.53	0.00	0.01	0.21	1.17	0.00	5.81	78.41	1.47	12.91	100.00	4.18	1.49
Steel Cans	31.58	0.21	0.00	5.06	0.35	0.00	0.00	21.02	53.90	19.45	100.00	0.70	0.24
HDPE	30.71	0.10	0.03	0.23	0.72	0.00	0.00	42.46	0.00	56.46	100.00	0.49	0.07
LDPE	37.68	0.08	0.03	0.19	0.58	0.00	0.00	51.11	0.00	48.01	100.00	0.61	0.07
PET	50.51	0.05	0.05	5.88	15.56	0.00	0.00	51.66	6.14	20.67	100.00	0.92	0.04

Exhibit 2-4 (Franklin Data)
Amount of Carbon Produced Per Ton of Product Manufactured from Virgin Inputs
Transportation GHGs Only

Type of Product	Transportation Energy (Million BTUs Per Ton of Product)	Average Fuel Mix (in Percent)					Transportation Energy Carbon Emissions (Metric Tons of Carbon Equivalent Per Ton of Product)
		Diesel	Residual Oil	Natural Gas	Electricity	Total	
New spaper	0.77	98.59	1.14	0.17	0.10	100.00	0.02
Office Paper	2.46	99.43	0.43	0.11	0.03	100.00	0.05
Tissue Paper	2.46	99.43	0.43	0.11	0.03	100.00	0.05
Corrugated Boxes	1.43	99.79	0.18	0.02	0.01	100.00	0.03
Folding Boxes	1.01	99.19	0.59	0.20	0.02	100.00	0.02
Aluminum Cans	5.73	37.53	62.07	0.00	0.40	100.00	0.12
Steel Cans	4.60	98.24	1.76	0.00	0.00	100.00	0.10
HDPE	1.15	54.50	19.32	24.66	1.52	100.00	0.02
LDPE	1.15	54.50	19.32	24.66	1.52	100.00	0.02
PET	3.27	79.65	16.63	2.42	1.31	100.00	0.07

Exhibit 2-5 (Franklin Data)
Greenhouse Gas Emissions Per Ton of Product Manufactured from Recycled Inputs
Process GHGs Only

Type of Product	Process Energy (Million BTUs Per Ton of Product)	Average Fuel Mix (in Percent)										Process Energy Carbon Emissions (MTCE Per Ton of Product)	Process Non-Energy Carbon Emissions (MTCE Per Ton of Product)
		Gasoline	LPG	Distillate Fuel	Residual Fuel	Biomass	Diesel	Electricity	Coal	Natural Gas	Total		
Newspaper	23.01	0.00	0.22	0.12	0.05	0.00	0.00	59.65	0.95	39.02	100.00	0.38	0.00
Office Paper	26.46	0.00	0.00	14.29	13.26	0.00	0.00	48.64	0.00	23.81	100.00	0.47	0.00
Tissue Paper	26.46	0.00	0.00	14.29	13.26	0.00	0.00	48.64	0.00	23.81	100.00	0.47	0.00
Corrugated Boxes	15.95	0.00	0.13	0.01	1.29	0.00	0.66	44.81	30.08	23.00	100.00	0.31	0.00
Folding Boxes	18.90	0.00	0.00	0.00	3.22	0.00	0.00	36.23	22.45	38.10	100.00	0.35	0.00
Aluminum Cans	40.34	0.00	0.00	0.00	3.10	0.00	0.00	39.96	0.00	56.94	100.00	0.65	0.00
Steel Cans	11.78	0.01	0.17	0.07	0.03	0.00	0.00	77.28	0.65	21.80	100.00	0.20	0.24
HDPE	12.68	0.00	0.21	0.00	0.00	0.00	0.00	99.79	0.00	0.00	100.00	0.21	0.00
LDPE	11.43	0.00	0.23	0.00	0.00	0.00	0.00	99.77	0.00	0.00	100.00	0.19	0.00
PET	21.87	0.00	0.12	0.00	0.00	0.00	0.00	99.88	0.00	0.00	100.00	0.37	0.00

Exhibit 2-6 (Franklin Data)
Amount of Carbon Produced Per Ton of Product Manufactured from Recycled Inputs
Transportation GHGs Only

Type of Product	Transportation Energy (Million BTUS Per Ton of Product)	Average Fuel Mix (in Percent)					Transportation Energy Carbon Emissions (Metric Tons of Carbon Equivalent Per Ton of Product)
		Diesel	Residual Oil	Natural Gas	Electricity	Total	
Newspaper	0.75	98.67	1.08	0.15	0.10	100.00	0.02
Office Paper	1.61	100.00	0.00	0.00	0.00	100.00	0.03
Tissue Paper	1.61	100.00	0.00	0.00	0.00	100.00	0.03
Corrugated Boxes	1.23	99.90	0.10	0.00	0.00	100.00	0.03
Folding Boxes	1.29	99.92	0.08	0.00	0.00	100.00	0.03
Aluminum Cans	1.65	100.00	0.00	0.00	0.00	100.00	0.03
Steel Cans	4.03	99.99	0.01	0.00	0.00	100.00	0.08
HDPE	1.74	100.00	0.00	0.00	0.00	100.00	0.04
LDPE	1.74	100.00	0.00	0.00	0.00	100.00	0.04
PET	1.74	100.00	0.00	0.00	0.00	100.00	0.04

Exhibit 2-7 (Tellus Data)
Amount of Carbon Produced Per Ton of Product Manufactured from Virgin Inputs
Process GHGs Only

Type of Product	Process Energy (Million BTUs Per Ton of Product)	Average Mix of Energy Sources									Process Energy Carbon Emissions (Metric Tons of Carbon Equivalent Per Ton of Product)
		Gasoline	Diesel	Oil	Steam	Electricity	Coal	Natural Gas	Other Fuels	Total	
New spaper	34.11	0.46	0.35	0.27	28.45	70.47	0.00	0.00	0.00	100.00	0.54
Office Paper	35.18	0.89	0.71	5.00	77.00	16.41	0.00	0.00	0.00	100.00	0.51
Tissue Paper	33.22	0.94	0.75	5.29	74.17	18.84	0.00	0.00	0.00	100.00	0.48
Corrugated Boxes	32.07	0.86	0.70	4.90	82.58	10.95	0.00	0.00	0.00	100.00	0.46
Folding Boxes	34.05	0.81	0.66	4.61	80.82	13.09	0.00	0.00	0.00	100.00	0.49
Aluminum Cans	216.24	0.00	0.00	1.93	1.08	72.01	1.25	23.68	0.05	100.00	3.62
Steel Cans	42.10	0.03	0.36	2.35	6.15	34.66	0.33	5.71	50.41	100.00	0.96
HDPE	37.29	0.00	8.10	0.00	1.69	23.09	0.00	42.27	24.85	100.00	0.72
LDPE	51.78	0.00	6.91	0.00	5.03	31.21	0.00	35.81	21.03	100.00	0.99
PET	62.51	0.00	5.61	0.00	27.37	34.99	0.00	10.89	21.14	100.00	1.25

Exhibit 2-8 (Tellus Data)
Amount of Carbon Produced Per Ton of Product Manufactured from Virgin Inputs
Transportation GHGs Only

Type of Product	Transportation Energy (Million BTUs Per ton of Product)	Average Fuel Mix (in Percent)			Transportation Energy Carbon Emissions (Metric Tons of Carbon Equivalent Per Ton of Product)
		Diesel	Natural Gas	Total	
New spaper	0.58	100.00	0.00	100.00	0.01
Office Paper	1.21	100.00	0.00	100.00	0.03
Tissue Paper	1.21	100.00	0.00	100.00	0.03
Corrugated Boxes	1.08	100.00	0.00	100.00	0.02
Folding Boxes	1.08	100.00	0.00	100.00	0.02
Aluminum Cans	5.29	100.00	0.00	100.00	0.11
Steel Cans	0.91	100.00	0.00	100.00	0.02
HDPE	3.72	53.25	46.75	100.00	0.07
LDPE	3.83	53.19	46.81	100.00	0.07
PET	2.48	57.44	42.56	100.00	0.05

Exhibit 2-9 (Tellus Data)
Amount of Carbon Produced Per Ton of Product Manufactured from Recycled Inputs
Process GHGs Only

Type of Product	Process Energy (Million BTUs Per Ton of Product)	Average Mix of Energy Sources									Process Energy Carbon Emissions (Metric Tons of Carbon Equivalent Per Ton of Product)
		Gasoline	Diesel	Oil	Steam	Electricity	Coal	Natural Gas	Other Fuels	Total	
New spaper	18.52	0.00	0.26	0.00	41.88	57.86	0.00	0.00	0.00	100.00	0.33
Office Paper	20.80	0.00	0.23	0.00	62.85	36.92	0.00	0.00	0.00	100.00	0.38
Tissue Paper	0.94	0.00	0.24	0.00	58.66	41.10	0.00	0.00	0.00	100.00	0.37
Corrugated Boxes	27.31	0.00	0.17	0.00	69.47	30.36	0.00	0.00	0.00	100.00	0.51
Folding Boxes	29.23	0.00	0.16	0.00	67.11	32.72	0.00	0.00	0.00	100.00	0.54
Aluminum Cans	46.04	0.00	0.10	2.57	0.00	35.51	0.00	61.82	0.00	100.00	0.74
Steel Cans	17.01	0.00	0.35	0.00	0.00	97.92	0.48	1.25	0.00	100.00	0.29
HDPE	17.85	0.00	0.27	0.00	0.00	99.73	0.00	0.00	0.00	100.00	0.30
LDPE	23.29	0.00	0.20	0.00	0.00	99.80	0.00	0.00	0.00	100.00	0.39
PET	27.84	0.00	0.17	0.00	0.00	99.83	0.00	0.00	0.00	100.00	0.47

Exhibit 2-10 (Tellus Data)
Amount of Carbon Produced Per Ton of Product Manufactured from Recycled Inputs
Transportation GHGs Only

Type of Product	Transportation Energy (Million BTUs Per Ton of Product)	Average Fuel Mix (in Percent)			Transportation Energy Carbon Emissions (Metric Tons of Carbon Equivalent Per Ton of Product)
		Diesel	Natural Gas	Total	
Newspaper	2.13	100.00	0.00	100.00	0.04
Office Paper	1.87	100.00	0.00	100.00	0.04
Tissue Paper	0.00	100.00	0.00	100.00	0.00
Corrugated Boxes	1.33	100.00	0.00	100.00	0.03
Folding Boxes	0.83	100.00	0.00	100.00	0.02
Aluminum Cans	0.90	100.00	0.00	100.00	0.02
Steel Cans	0.82	100.00	0.00	100.00	0.02
HDPE	0.83	100.00	0.00	100.00	0.02
LDPE	1.56	100.00	0.00	100.00	0.03
PET	1.56	100.00	0.00	100.00	0.03